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TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 692

METHODS OF RECORDING RAPID WIND CHANGES

By A. Magnan

Jahrbuch No. 4 (1929) des Forschungs-Institutes
der Rhön-Rossitten-Gesellschaft

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM NO. 692

METHODS OF RECORDING RAPID WIND CHANGES*

By A. Magnan

The purpose of our research was to determine the rapid changes of air currents which impose varying stresses on the wings of an airplane. We attempted to express in figures the turbulence of the air, which perhaps plays some role in the behavior of airplanes in flight, as well as in the realization of certain methods of gliding flight. This is the reason which has led us to conceive and develop the experimental equipment described herein.

HOT-WIRE ANEMOMETER

A hot-wire anemometer includes a platinum wire F (fig. 1), a battery B_1 supplying the heating current, and an ammeter G, with shunt S, for recording this current. The wind blowing against the red-hot wire, cools it, as a result of which the intensity of the current is increased. The curve in Figure 2 represents the intensity variation in the wire under these conditions and proves that the sensitivity of such apparatus drops at such a rate as to be practically useless above a 5 m/s velocity.

To overcome this objectionable feature, we added a compensating battery B_2 and a resistance R (fig. 1), by means of which the shunt current can be eliminated when there is no wind. On top of that, this shunt, instead of having an invariable resistance is, on the contrary, a wire sheltered from the wind, and whose resistance increases considerably with the current passing through it. Under these conditions the readings on the instrument are, as seen in Figure 3, fairly proportional to the velocity of the air current.

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* "Méthodes de mesure des variations rapides du vent." Jahrbuch No. 4 (1929) des Forschungs-Institutes der Rhon-Rossitten-Gesellschaft, pp. 92-100. Lecture delivered at the First Scientific Glider Session.

Figures 4 and 5 illustrate a hot-wire anemometer of our own design. The hot wire is mounted to a support at the end of a tube (fig. 4) and connected by wires to a control panel, on which rheostats R, voltmeter V, ammeter A, milliammeter MA, and commutators are grouped. For ordinary wind studies the platinum wire is protected by a wire-mesh hood which reduces the velocity of the wind to about half. (Fig. 5.) The device may be given any desired sensitivity by appropriate size of mesh.

The wind velocity can be read on the voltmeter V or else recorded by oscillograph. The period of this oscillograph is short, the moving part is an iron plate orientated by a fixed magnetic field and deflected more or less from equilibrium by a transverse field produced by the current to be measured.

In the experimental study of this anemometer we wanted to ascertain whether it would be sensitive enough to react to very rapid air pulsations. To this end we placed a hot wire inside of an acoustic pipe vibrated by compressed air. Using a lens, we obtained an image of the anemometric wire on a photographic film. In spite of the small variation in velocity, the wire is subject to temperature changes leaving a clear record on the film, from which the period of vibration of the acoustic pipe could be defined. (Fig. 7.) We also placed in this same pipe the hot wire of an anemometer, and the oscillogram revealed a record which brings out the irregularities of the air pulsations in the pipe. (Fig. 8.)

The hot-wire anemometer is an instrument of comparison which must be calibrated by the agency of absolute aerodynamic measurements. Heretofore, we were contented with calibrations effected in a small wind tunnel and in the Eiffel and in the Issy-les-Moulineaux wind tunnels, whose different velocities had been determined by static pressure or Pitot tube measurements. The aspect of the experimental curve, obtained in the Eiffel tunnel and plotted with the speed of the air current (in meters per second) as abscissas and the difference in potential at the shunt terminals as ordinates, presents a scale that is very sensibly proportional by virtue of an expedient control of the shunt properties: length, diameter, and air density in which we placed it, the shunt being housed in a kind of lamp.

DIRECTION INDICATOR WITH TWO HOT WIRES

In wind studies it is necessary to know, aside from the velocity, its instantaneous direction, hence a direction instrument of approximately the same period as the speed indicator is needed. Our aim was to use the hot wires also for recording the oscillations of the air current and with that in mind we developed a simple direction indicator by placing two hot wires symmetrical to one another in a plane passing through the axis of a cylinder and parallel to this axis. (Fig. 9.) These two wires F_1 and F_2, forming two leads of a Wheatstone bridge, complete with two resistances R_1 and R_2 and an amperemeter or galvanometer G, the circuit shown in Figure 10. A set of storage batteries B feeds the bridge at constant tension. The bridge being balanced in still air and the wires being brought to incandescence when the wind blows in a direction parallel to the plane of symmetry of the apparatus, the two wires are cooled at the same rate and the current remains the same in each; then the galvanometer records no deflection. When the wind is from the right, one wire cools off more than the other, resulting in a current in the galvanometer which causes it to deflect. When the wind blows from the left the galvanometer deflects in the inverse sense. In this manner the amount of current which passes through the bridge as result of the variations in resistance of the hot wires can be utilized for indicating the slope of the wind to the plane of symmetry of the instrument. Moreover, appropriate choice of the constants of the instrument makes it possible to render the current which passes through the galvanometer proportionate to this slope.

In a direction indicator the hot wires, fastened on a cylinder parallel to its generatrices, are connected by wires to a control panel which contains resistances R, ammeters for reading the intensity in the hot wires, and milliammeter MA graduated with the zero in the center of the dial and deflecting in one or the other direction according to the direction of the current which passes through the transverse arm of the bridge.

The wind direction can be read on the milliammeter MA or may be recorded by an oscillograph which does not differ from that of the velocity except for the lower resistance of the coil and the median position of its zero.

Such a direction instrument is of no practical use unless its readings are a function only of the wind direction and not of both direction and velocity. Regardless of what one may think, our experience has been that the calibration of our instrument was practically independent of the velocity within very wide limits. The first tests were carried through in our own small wind tunnel up to 20 m/s; up to this velocity the operation was correct. In the large tunnel at Issy-les-Moulineaux, where the velocity was raised to 45 m/s, the calibration again maintained sensibly the same figure.

CONVERTERS

Another instrument developed by us is called a converter. It permits a simultaneous record of the intensity of a variable current and the derivative of this intensity with respect to time. The principle of this instrument is as follows:

A hot-wire instrument produces a current whose intensity i or electromotive force e is proportional to the quantity to be measured, i.e., velocity V, and inclination α, or orientation β, of the wind. A first frame of galvanometer I is placed in a magnetic field. (Fig. 11.) This frame I gives the measure of i or of e as function of the time, for example, by means of a spot, and records these angular displacements on a photographic film in uniform motion. A second frame II, solidly fastened to frame I, and in the same magnetic field, yields an induced electromotive force proportional to di/dt or de/dt, because its angular movement is proportional to i or to e. Lastly, a third frame III, disposed in another magnetic field measures the current produced by this electromotive force in a circuit wherein only the ohm resistance is considered, the reaction of the small on the large frame being negligible. The instrument consists of two electromagnets - one large, the other small - one carrying three large frames, the other, three small frames. All these frames are placed in the air gap of pole pieces, each with three cogs. The large electromagnet consumes about 25 watts and gives a field of about 4,500 gauss, the small one consumes 12 watts and supplies a field of about 5,000 gauss.

The largest of the electromagnets carries the three

frames with double winding - one for studying the wind velocity, the other two, its inclination and orientation. The resistances of the windings are approximately 1ω for all frames II, 30 ω for frames I of the direction instrument, and 250 ω for frame I of the velocity indicator; that of the small frames is 1 ohm.

MOBILE LABORATORY

Since a comparison of the variations in velocity and in direction, produced at a given instant in the same wind, seemed mandatory, we attempted to record velocity and direction on the same film.

To this end we fitted a laboratory truck with a table and a special control panel. (See fig. 12.) The table holds the film roller mechanism with its electric motor and a lamp for forming luminous images. This film roller mechanism is equipped for automatic developing and fixing. It includes a magazine with photographic paper of 6 cm width, around which is disposed a series of rollers which feed the sensitive film in front of the window or spots in the oscillograph and where an image is produced, over a roller impregnated with developer, then over the roller impregnated with a fixing agent. Another roller finally ejects the developed and fixed film. These rollers are rendered solid by an endless chain driven from an electric motor. A second table carries a wind tunnel for calibrating the instruments. Lastly, a chest holds the storage batteries for operating the hot-wire instruments and a "Homelite" charger set.

EXPLORATION OF SPEED AND DIRECTION OF WIND

We have used these instruments from 1922 to 1929 for exploring the structure of the natural wind. Our chief aim was to gain information in a maritime region, especially, such as the low and flat island of Ré afforded. At the beach of la Couarde we erected a mast about 11 m (35 ft.) high in the sand, so that the waves washed about its base. A carriage carrying the hot-wire instruments permitted any desired height. First of all it was desirable to compare the sensitivity of the employed oscillographs. To this end we carried the current, supplied by one direc-

tion indicator with two hot wires placed 10 m (32 ft.) above the ground, simultaneously in two oscillographs and simultaneously recorded the variation in inclination of an east wind on one film. Figure 13 shows that the obtained records are identical.

Then we analyzed the interference of the instruments on each other. We placed two inclination indicators, 42 cm apart, 10 meters above the ground. The experiment proved the interference to be small, although the discrepancies manifested in the record do not permit a definite conclusion as a result of the spacing. On the other hand, the record in Figure 14, obtained by placing the two indicators 9 cm apart and at the same height as before (10 m), readily shows the parallelism of the curves, but it also reveals that the spacing of these records is no longer the same as the spacing of the zeros. The examination of these records and of the disposition of the instrument reveals that the interference here produces the same result as if the upper inclination instrument had encountered an up-wind, and the lower one, a down-wind; it indicates an increase in velocity between the two cylinders.

At the isle of Ré we recorded the instantaneous velocity of winds of divers origins. Thus, Figure 15 shows the physiognomy of a sea breeze whose most significant variations did not exceed a third of the mean velocity. Figure 16, in contrast, is a record of a land breeze from the northeast, taken 10 meters above the ground. Here the amplitude of the variations of the velocity is much greater than on the preceding film, the latter exceeding at times 0 to 14 m/s within less than 2 seconds.

We also had occasion to study a windstorm from beginning to end. (Fig. 17.) During the storm, abrupt changes in velocity of 7 m/s within 1/5 of a second were common, at the same time as the inclination presented oscillations of great amplitude at this point.

When the storm died down the velocity, which still averaged 10 m/s, reassumed a regular form as is often the case, and the inclination no longer revealed significant changes.

The study of the variations in velocity and inclination of the wind with the altitude, has confirmed our previous results and proves that the velocity increases with the altitude, although the amplitude of its variations diminishes at the same time as the amplitude of the oscil-

lations of the inclination decreases with the height. (Figs. 18 and 19.) We further verified that in sea breezes the velocity at 10 meters altitude is almost constant for several seconds. (Figs. 20 and 21.)

PERIODICITY OF WIND

An analysis of the wind-velocity curves from various sources reveals a more or less distinct periodicity. Even if this periodicity does not actually exist in the strict sense of the word, it seems as if ordinary winds contain disturbances, the length of which is consistently the same. Examination of the records (figs. 22 and 23) reveals at first glance smaller disturbances inside of larger disturbances, and of a certain periodic recurrence. On the other hand, if one considers the recorded mean velocity of the wind with the duration of its disturbances which appear most regular, it will be noted that the product of these two quantities - a product which represents the length of the disturbance (which is the wave length if the phenomenon was periodic) - has an almost constant value of about 375 meters, according to the appended tabulation:

Place	Direction	Vm	P	λ
Plains of Crau	north	9 m/s	41 s	369 m
"	"	6.20 "	60 "	372 "
Shore of Havre	southeast	3.80 "	103 "	391 "
"	"	4.20 "	93 "	390 "
Paris	west	7 "	55 "	385 "
Shore of Sables	southeast	5 "	77 "	385 "
Mount Ventoux	north	8 "	48 "	384 "
Ocean (Conquet)	west-southwest	8 "	47 "	376 "

The greater the velocity the shorter the period, and the whole seems to proceed as if there were slices of air of stated length and as if the slices separated with a more or less great mean velocity. If this is the case,

then the slices of the air in motion would have a constant length independent of the force of the wind.

A record of the velocity obtained at 300 m (985 ft.) revealed much greater oscillations with a duration of 150 seconds.

When one considers the mean velocity, which is 15 m/s, with this 150 seconds' duration, the product is 2,250 meters, that is, to say, six times the 375-meter wave length established for the winds studied near the ground. It is seen that the large disturbances consist of a succession of smaller disturbances, some of which have a duration of around 25 seconds, and a wave length of about 375 meters.

What conclusions can be drawn therefrom? Does it not prove the existence of an undulatory periodic motion in the atmosphere similar to that observed on the ocean? Is it not proof of the existence of aerial swells or billows?

Mr. Fortant has posed the question and he has demonstrated its significance, which he will try to settle from the point of view of aviation, in a relative study of the undulatory movements of the atmosphere and in their effect on aircraft.

THERMAL WINDS

We likewise attempted to study the wind structure rendered upward by the heating of the ground in desert countries. These experiments were made in the Médenine region, in the southern part of Tunis. We used a pipe 10 meters long as mast, and three guy wires. The hot-wire instruments were mounted in a laboratory trunk. The operation in practically zero wind and by an atmospheric temperature of 27° in clear weather, resulted in the records given in Figures 24 and 25. The outstanding feature, when examining these records, is that the air current studied 10 meters above the ground is in its aggregate distinctly upward with an average of from 6 to 7°. It likewise appears that this air current is more disturbed at 10 meters than at 1 meter above the ground. This agitation may be explained by the passage of a series of eddies with vertical axes, similar to those observed on the desert sand, and which move in the direction of the wind when it exists simultaneously with a horizontal air current.

MEASUREMENT OF ACCELERATIONS AND ANGULAR VELOCITIES OF THE WIND

By this use of the instruments, we were able to begin the determination of the accelerations and angular velocities which are encountered in the wind.

Here is a simultaneous record (fig. 26) of the variations in inclination of a 10-12 m/s north-northwest wind, taken 5 meters above the ground at Marignane. The maxima observed here are $+27.5^\circ$ and -30°. At the top is the record of the angular velocities furnished by the converter. The maximum here is 200° per second, whereas the angular velocity shows 53° per second. It will be noted that this velocity changes from $-108^\circ/s + 96^\circ/s - 120^\circ/s$ and $+100^\circ/s$, within 1/3 of a second.

Figure 27 is of interest in so far as it contains a simultaneous record of velocity and inclination of a light north-northwest breeze taken at 30 m (100 ft.) altitude.

The velocity seems regular enough, whereas the inclination reveals variations not exceeding 7 to 8° in amplitude. Also, the curves of the accelerations and of the angular velocities themselves are not very uneven. As to the acceleration, the maximum does not exceed 8 m/s^2, the average being 3 m/s^2. The maximum angular velocity is 90° per second, and the average, 26° per second.

As a result of our experiments, it may be stated that the accelerations of a windstorm coming from the sea, are not much more significant than those of a wind having moved with friction over the ground and having a velocity of no more than 3 to 5 m/s. The remarks which can be made about the inclination here are of the same order as those cited previously. Thus, a sea breeze recorded at 10 m (33 ft.) above the ground, presents the lowest angular velocity, whereas the terrestrial winds manifest all amplitudes of inclination and angular velocities.

MEASUREMENT OF TURBULENCE

By virtue of these studies of angular velocity, we have been able to take up the measurement of the turbulence of the air.

With a given air mass, at rest or animated by an aggregate motion of uniform translation V, we consider as turbulence all supplementary motion with variable velocity in size or direction which is superposed on this translation. To an observer carried away by the wind with mean velocity, as, for instance, in a free balloon, the motions of the air amenable to registration by the anemometers on board, constitute the turbulence of this air.

Obviously, this definition is arbitrary, since it depends upon the choice of instruments used to record the characteristics of the wind. With sensitive equipment that can be readily balanced, such as ours, the discernible turbulence is certainly much smaller, in general, than that which can have any appreciable effect on an airplane or even on a bird. In our previous studies we used wind-speed and wind-direction recorders. The instruments were grouped at a point O, and we recorded on an endless film the values of the velocity W of this wind, its inclination α, and its orientation β, with respect to the mean track of the wind.

During the duration of a record, the wind has a mean velocity V, defined in magnitude and direction. If we arrange for each instant wind velocity W and the mean V, we obtain a vector u that represents, for each instant, the turbulence of the air mass passing the instruments located at point O. (Fig. 28.) In addition, we have shown in the preceding sections the motion, which is represented by this vector u, to spread more or less with the air mass for some time, becoming more or less distorted in the manner of a sound wave in the air. It is, then, possible from the graphs of an anemometric strip that carries the records of the speed, the direction and inclination of the wind at a point O, records obtained between intervals T and T + t, to demonstrate at least approximately, what the value of vector u amounted to at each instant of time interval t along the line of the current that passes through the point O.

The motion of turbulence u being assumed nearly constant, from the succession of measurements of u effected at O within T and T + t, it was deduced that the distribution of turbulence in the atmosphere was similar to that figured at (a) interval T, and transferred as indicated in the figure; (b) similar to interval T + t. (Fig. 28.)

Grouping of the vectors u along the divers lines of the parallel current, made it possible to characterize the turbulence of any air mass in motion.

In conformity with the foregoing, the anemometric films containing for each instant of V, α and β, permit us to give the geographic distribution for intervals between T and T + t of the turbulence along the line of the air current.

The equations of interest for the equilibrium in birds or airplanes, include the acceleration and angular velocity of the relative wind, quantities which can be deduced from the data, for each instant, of the speed and inclination of the wind, but in doing so, direct measurements are absolutely essential if the operations of tedious derivations are to be avoided. In principle, there is no difficulty in effecting their measurement in an airplane by the same methods which we employed on the ground, consisting of deriving electrically the current, rendered proportionate either to the speed or to the inclination (or orientation of the wind). The added stresses imposed by the wind on a glider are definitively due to the acceleration of the turbulence of the air. The importance of these stresses can be readily ascertained by constructing in magnitude and direction, at each point of the atmosphere, the vector which represents the acceleration of the turbulence. This vector is the geometrical sum of the acceleration $\frac{dw}{dt} = \gamma$ of the wind and of the instantaneous variations $\overline{W}\,\omega$ in wind velocity due to its rotation. (Fig. 29.)

We also measured over a large portion of the curves recording the speed, acceleration, inclination and angular velocity of the wind at Marignane, 30 meters above the ground (fig. 27), every 3 mm, the turbulence at various instants, as well as the turbulence acceleration.
The appended table gives the figures attained by the previously described method for a portion of the curve (1 second).

	W	γ	I	ω 0/s	ω rad/s	W ω	Γ
1	4.90	to 3.84	9.07	-56	-0.98	-4.85	6
2	4.75	-4.23	11.6	+27	+0.47	+2.2	5
3	4.10	-2.8	8.75	+30	+0.52	+1.15	3.5
4	4.3	-3.1	7.7	+54	+0.94	+4.05	2
5	4.2	-2.7	4.57	+37	+0.212	+0.89	2.1
6	4.5	-0.96	5.04	-23	-0.134	-0.56	1.4
7	4.25	-2.3	9.07	-69	-1.2	-5.1	5.9
8	4.25	-9.2	9.92	-41.5	-0.72	-3.05	10
9	3.75	-6.7	10.53	0	0	0	0
10	4	+1.92	10.2	- 9	-0.156	-0.63	2
11	3.9	+3.84	10.8	-25.5	-0.445	-1.12	4.5
12	3.9	0	12.6	0	0	0	0
13	4	+1.54	11.5	-69	-1.2	-4.8	5.5
14	4.1	+2.3	13.25	+76	+1.32	+5.4	6.1
15	4	-2.9	7.7	+23	+0.4	+1.6	2
16	3.9	-3.85	8.7	- 4.6	-0.08	-0.31	4
17	3.9	-4	11.3	-32.3	-0.56	-2.24	4.5
18	4	-1.92	11.2	+ 9.2	+0.16	+0.64	2
19	4	0	10.45	0	0	0	0
20	4	0	10.6	-83	-1.44	-5.76	6.1
21	4.05	+0.96	12.25	+ 1.8	+0.037	+0.092	1
22	4	-2.1	10.3	- 7	-0.124	-0.50	2.5
23	3.9	-4	11.6	-18.4	-0.31	-1.22	4
24	4.1	+1.15	11.45	-18.4	-0.32	-1.42	1.1
25	4.25	-1.15	12.9	+ 4.6	+0.08	-0.34	1.1
26	3.9	-4.8	12.0	0	0	0	0
27	4	-0.96	12.4	+25.4	+0.435	+1.75	1
28	4.25	+3.1	11	0	0	0	0
29	4.3	+5.2	11.1	-25.4	-0.435	-1.86	5.4
30	4.25	+1.92	12.25	-11.5	-0.2	-0.85	2

We then plotted, in Figure 30, the actual value of resultant Γ, which represents the vector (acceleration) of the turbulence, as well as its direction with respect to the mean axis of the wind for the time interval between the fourth and fifth second. It is readily seen that the value for the turbulence is distinctly different from that for its direction during this time lapse. This variation brings out a more or less periodic undulation of the wind similar to a sort of aerial billow, as well as a turbulent aspect at certain moments.

In order to study the motions of the air, and in particular, to ascertain whether it would be possible to de-

tect the nearness of the ground from the increase in turbulence, we developed a test instrument intended for use on the ground and which was to enable us to figure direct, not the turbulence itself, but rather one component of the rotation, that is, the absolute value of the mean angular velocity.

A direction instrument with two hot wires F_1 and F_2, balanced by two resistances R_1 and R_2, is operated by a battery P. The galvanometer of the bridge is replaced by the primary of a transformer T computed for frequency 3. The secondary of the transformer is hooked to a special, long-period, thermal galvanometer G, operated by voltmeter. This galvanometer is of the type studied for hot-wire altimeter. Figure 31 shows this galvanometer, which chiefly consists of a double platinum wire held tight by a bronze spiral carried by a shaft mounted on pivots. On this shaft is also the mirror necessary for the photographic record of the indications of the instrument. The elongation of the wire under the effect of heating, induced by the current in the galvanometer, determines the rotation of the mirror.

But in order to insure sufficient sensitivity and duration of balance, it was necessary to protect the expansible wire from cooling in the open air. The instrument was housed in a carefully evacuated tube. Its sensitivity was greatly enhanced and its period of balance considerably prolonged. The record is a mean value of the angular velocity of the wind, a quantity which is a function varying in the same sense as the turbulence. The transformer employed has a 4 by 4 centimeter iron core, on which the two coils are wound. The thermal galvanometer has an approximate deflection of 125 millimeters per milliampere on a scale placed at 1 meter. It is practically insensitive to vibration or shocks, provided it is mounted on rubber. The balancing takes about 6 seconds.

Translation by J. Vanier,
National Advisory Committee
for Aeronautics.

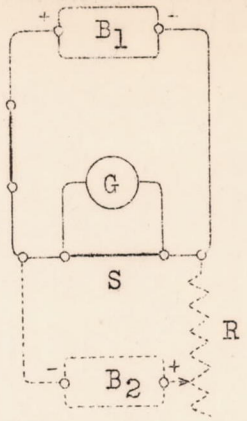


Fig. 1

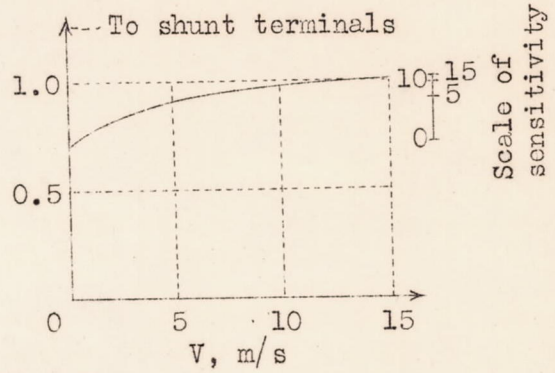


Fig. 2

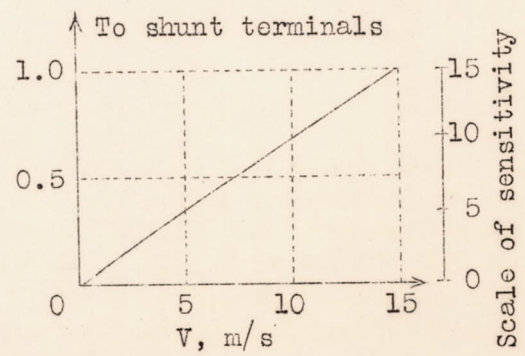


Fig. 3

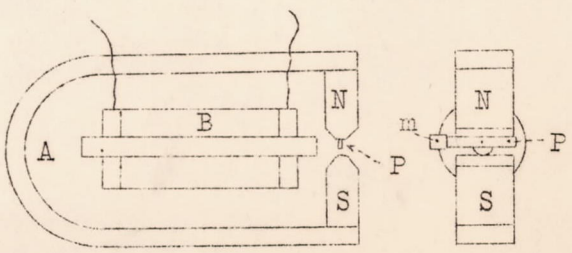


Fig. 6

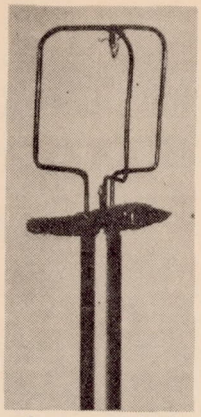


Fig. 4 Anemometric wire mounted on base.

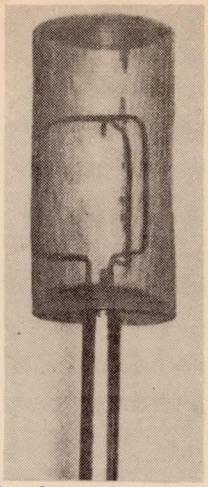


Fig. 5 Anemometric wire with cover.

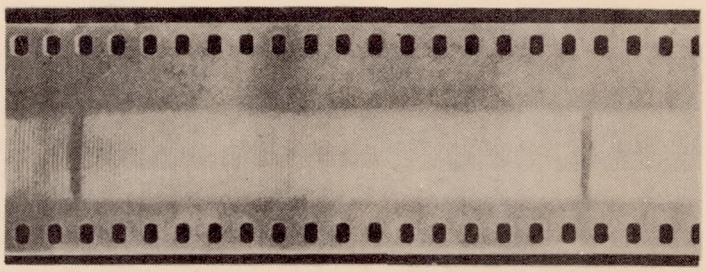


Fig. 7 Hot wire anemometer record of periodic variations in speed produced by the sound waves at the mouth of a sonorous pipe vibrated by compressed air.

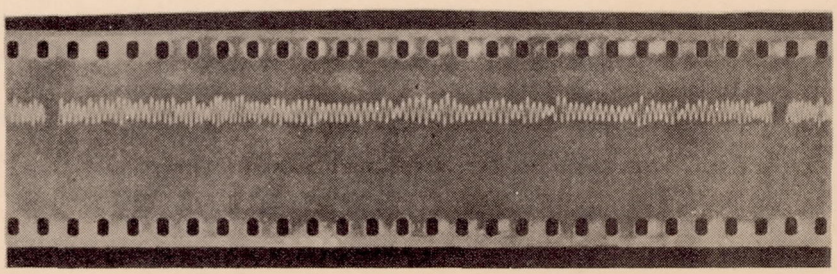


Fig. 8 Oscillograph record of fundamental sound of an acoustic pipe, (130 periods per sec.)

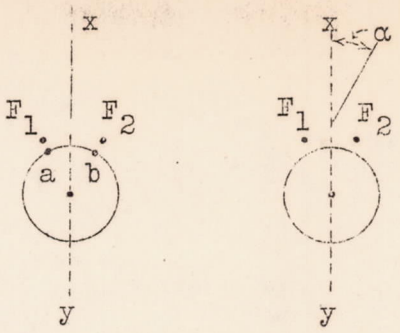


Fig. 9

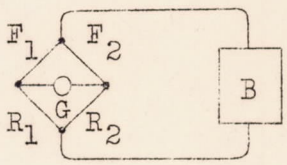


Fig. 10

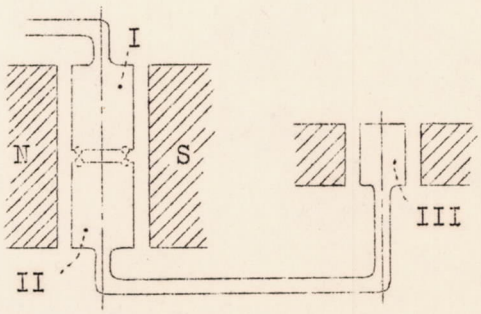


Fig. 11

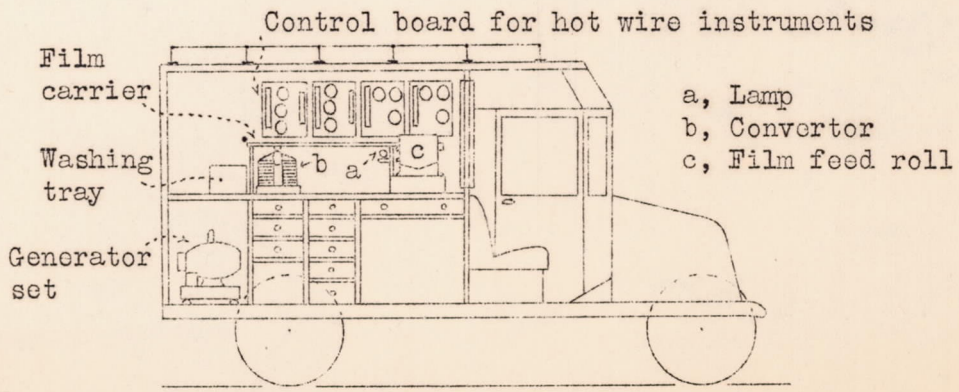


Fig. 12 Side view of truck showing installation.

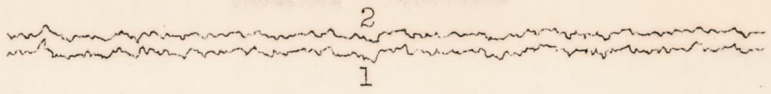


Fig. 13 Simultaneous records of inclination of an east wind, taken at Couarde, Sept. 15 1925 with two oscillographs 1 and 2 receiving the same current supplied by a hot wire indicator, 10 m above the ground. Film speed 1 sec. = 5 mm, Scale of inclination 10 mm = 16°

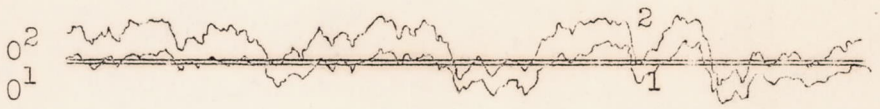


Fig. 14 Simultaneous records of inclination of an E N E wind, obtained at Couarde, Sept. 15 1925, with two hot wire indicators, the second (2) being placed 10 m above the ground and 9 cm above the other (1). Film speed, 1sec. = 13 mm, Scale of inclination, 10.5 mm= 16°. 01 and 02 = line of zero inclination of indicators 1 and 2.

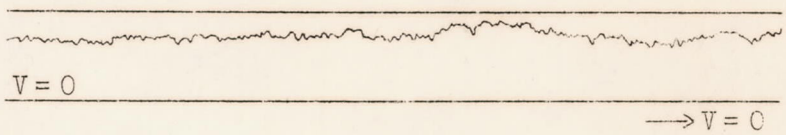


Fig. 15 Record of the velocity of a W S W wind, obtained at Couarde, Sept. 2 1925, the instrument being placed 2 m above ground level on water. Film speed, 1 sec. = 6.25 mm. Scale of speed, 2 mm per m/s. V = 0 = zero speed.

Fig. 16 Record of the speed of a N E wind, made at Couarde, Sept. 7 1925, 10 m above the ground. Film speed, 1 sec. = 5 mm. Scale of speed, 2 mm per m/s. V = 0 = zero speed.

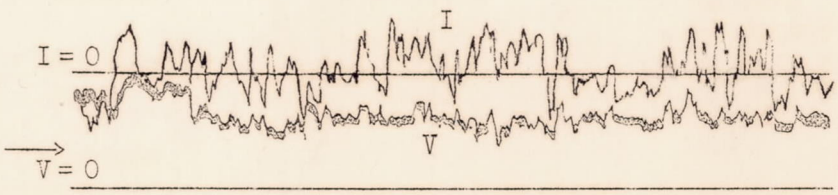


Fig. 17 Simultaneous records of speed V and inclination I of a W S W wind, taken at the height of a storm.

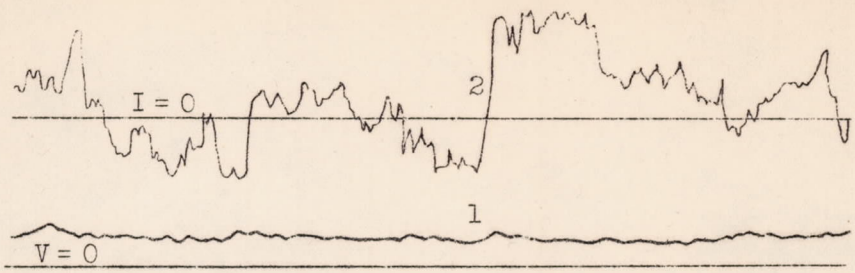


Fig. 18

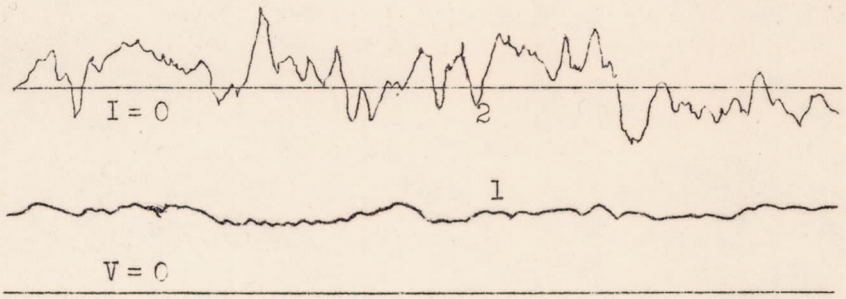


Fig. 19

Figs. 18 and 19 Simultaneous records of the speed (1) and the inclination (2) of a N W wind, at Couarde, Sept. 5 1925. In Fig. 18 the instruments were placed 5 m, and in Fig. 19, 10 m above the ground. Film speed, 1 sec. = 7.6 mm. Scale of speed, 2 mm per m/s. Scale of inclination 10.5 mm = 16°. V = 0 = zero speed. I = 0 = zero inclination.

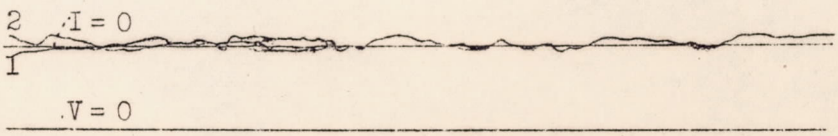


Fig. 20

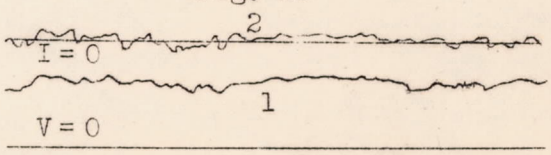


Fig. 21

Figs. 20 and 21 Film speed, 1 sec. = 17 mm. Simultaneous records of speed (1) and inclination (2) of a W wind, Couarde, Sept. 18 1925. In Fig. 20 the instruments were 5 m, and in Fig. 21 10 m above the ground. Scale of speed, 2 mm per m/s. Scale of inclination 10.5 mm = 16°. V = 0 = zero speed. I = 0 = zero inclination.

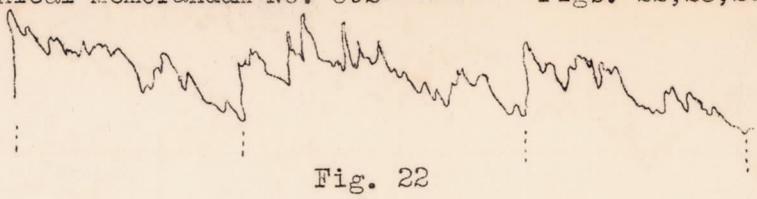


Fig. 22

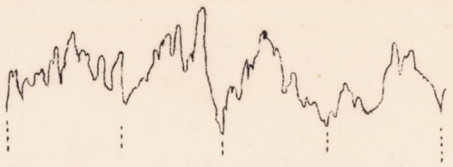


Fig. 23

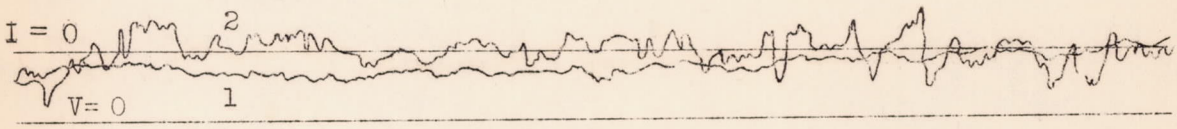


Fig. 24

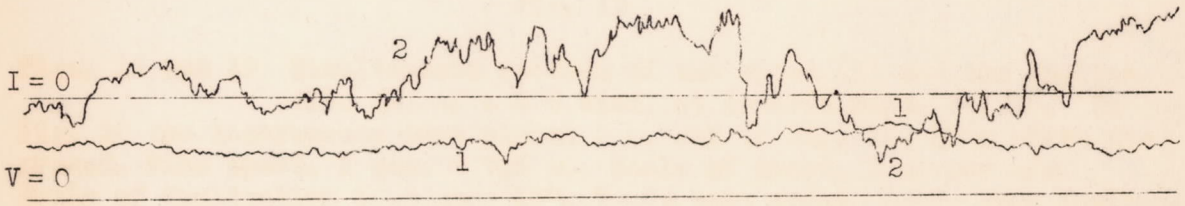


Fig. 25

Figs. 24 and 25 Simultaneous record of speed (1) and inclination (2) of an air current taken near Médenine, Oct. 21, 1925. In Fig. 24 the instruments were 1 m and for Fig. 25, 10 m above the ground. Film speed, 1 sec. = 6 mm. Scale of speed, 15 mm per 2.4 m/s. Scale of inclination 0.95 mm = 1°. V = 0 = zero speed. I = 0 = zero inclination.

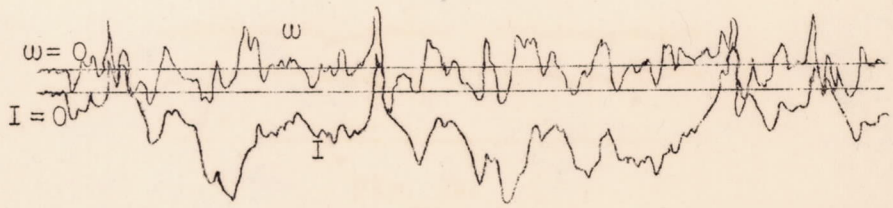


Fig. 26

Fig. 26 Record of inclination I and of angular velocity ω of a 10-12 m/s N.NW wind at 5 m above the ground. Location, Marignane Oct. 24, 1927. Scale of inclination, 1 mm = 1°. Scale of angular velocity, 1 mm = 12°/s

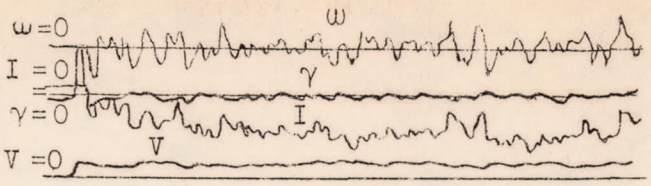
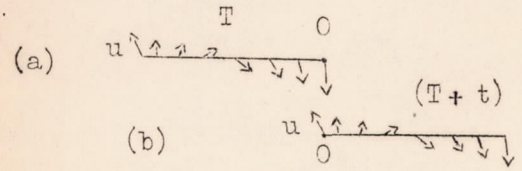


Fig. 27 Simultaneous records of speed V and inclination I and their derivatives γ and ω for a N N W wind, Marignane, Oct. 25 1927 30 m above the ground. Scale of speed, 0.75 mm = 1 m/s. Scale of inclination, 1 mm = 1°. Scale of acceleration, 1 mm = 5 m s/s^2. Scale of angular velocity, 1 mm = 12 °/s.



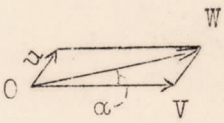


Fig. 28

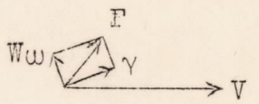


Fig. 29

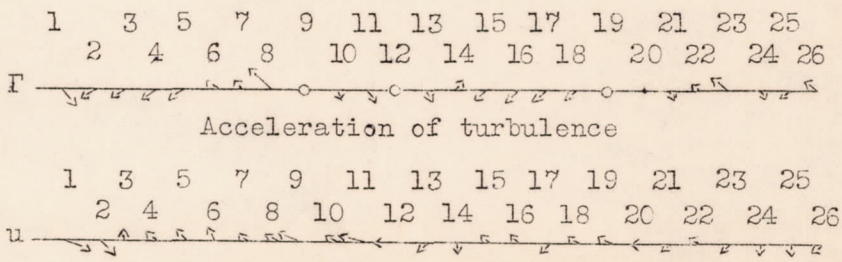


Fig. 30 Actual values of the resultant Γ representing the vector acceleration of the turbulence u as well as its direction for the N N W wind at Marignane of Fig. 26.

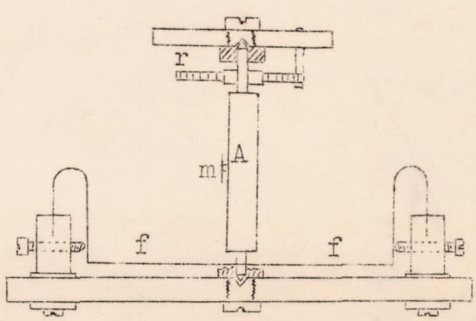


Fig. 31

Galvanometer